OCEAN TEMPERATURES OFF THE COAST OF PERU

By R. E. COKER
Assistant in Charge of Scientific Inquiry, Bureau of Fisheries

Temperate Waters in Tropical Regions

No feature of the coast of Peru is more significant as affecting the character of its marine fauna and flora than the Humboldt, or Peruvian, Current. It is scarcely necessary to apply the limitation "marine," since the climatic conditions of islands and mainland are so profoundly affected by the contiguity of a cold stream and land warmed by a tropical sun that no animal or plant life, terrestrial as well as marine, can escape its effect. In a previous paper[1] on the general fishery conditions of the coast, I stated:

> To find upon the coast of the United States a summer temperature of the ocean water corresponding to that of Callao at 12° S. one would go to about the latitude of New York on the Atlantic side (41° N.) or Monterey on the Pacific (36° N.). The Peruvian Current, in conjunction with other factors, particularly the constancy of the winds of the coast, produces a relative uniformity of temperature conditions. There is little variation in the water temperature from hour to hour during the day, little difference from month to month during the year, and a relatively small change from latitude to latitude. It is probable that such variations as are found are due more to very local conditions, or to the swinging of the current, than to seasonal changes or differences of latitude. . . . . .
>
> With such low water temperatures a tropical fauna is, of course, absent. Corals are wanting, sponges nearly so, and the general character of the fauna and flora of the region is such as would ordinarily be found in much higher latitudes.

Comparatively recently several reports on the fauna and flora of the coast have appeared[2], based on the writer's collections; it may, therefore, be of particular value to give in greater detail the observations upon which the general statements were founded. A qualification is freely made that the temperature records cannot pretend to the most desirable scientific accuracy. The best instruments were not regularly available. The observations were made during nearly twenty months of travel in 1907-08, often under rather difficult conditions and with other objects in view. While it may be regretted that the need of an adequate supply of tested thermometers was not anticipated, it is clear that a slight error in individual readings will not affect the bearings of the data upon the general conditions of animal or plant life.

Two striking illustrations of the effect of the temperature upon the distribution of semi-aquatic animals may be mentioned. A fur seal is familiar to the Peruvian fishermen under the name of *lobo fino,* or *lobo de los pelos,*

[1] "The Fisheries and the Guano Industry of Peru," Proceedings of the Fourth International Fishery Congress, *Bull. Bur. of Fisheries*, Vol. 28, 1908, Pt. I, pp. 333-365.

[2] Mainly in *Proc. U. S. Natl. Museum*, Vol. 37, 1909, and Vol. 38, 1910, *U. S. Natl. Museum Bull. 95*, 1917, and *Memoirs Torrey Botan. Club*, Vol. 15, 1914.

and seems to range as far north as Paracas Bay at 14° S. latitude, where it is supposed to breed. The penguin, generally associated with higher latitudes, is here common within the tropics. I observed it as near the equator as the Lobos de Afuera islands, about 7° S. It may be added that while sea turtles are common on the coast it could not be learned that they made nests upon the beaches south of Tumbes, 3½° from the equator, and it is extremely improbable that they would breed on the colder shores to the south.

There is an abundance of pelagic life that is not characteristic of tropical latitudes. The influence of the ocean temperature conditions upon the marine fauna and flora is, indeed, too complex and far-reaching to be susceptible of brief analysis. In the first place, the proximity of cold waters and warm lands creates a condition that makes condensation and rainfall virtually impossible. Innumerable small surface organisms are saved from the destruction that might be caused by excessive precipitation; and the clear sunlight is of inestimable value for the growth of the minute plants that form the basis of the food supply of all the marine animals. The higher value of colder waters for absorption of the gases necessary for organic life, the remarkably slight daily and seasonal variations of temperature, the absence of conditions to promote evaporation—these and other features of the Peruvian waters must be reflected in one way or another in the abundance and variety of the animal and plant life.[3]

Uniformity in Temperature Conditions

It is probable that such variations as are found are due more to very local conditions or to the swinging of the current than to seasonal changes or differences of latitude. For example, at Lobos de Afuera (7° S.) during the twelve days March 16 to 28 (range of temperature 19°-22.4° C.) the average of the records taken at noon was but three-tenths of a degree Centigrade higher than the average of those at 8 A. M., or two-tenths higher than the records at 8 P. M.; and at Lobos de Tierra (6½° S.), nearer shore and less directly in the current, the noon average was only seven-tenths of a degree greater than the identical averages of morning and evening readings. The extreme readings during nine days of bright weather were but one degree apart (20°-21° C.).

These records at the islands of Lobos de Afuera and Lobos de Tierra were made at the very close of the summer. At the beginning of the following summer (December) records were again made at the same places, with the result that the averages were 2.3° and 1.7° lower, respectively, than before. It may be noted that at the beginning of summer the current is flowing from a region which has been passing through winter, while at the

[3] "No waters in the ocean so teem with life as those on the west coast of South America," says Buchanan (J. Y. Buchanan: On the Similarities in the Physical Geography of the Great Oceans, *Proc. Royal Geogr. Soc.*, Vol. 8, 1886, pp. 753-770, with map and diagrams; reference on p. 766.)

end of summer the current is passing from a region that has been in summer, and this may partly explain the fact that the early summer temperature noted was lower than the late summer temperature of the preceding season. It is possible, too, that conditions of a more temporary nature may have caused the small but readily appreciable differences.

At Callao, 12° S., I found summer water temperatures of 15°-19° (59°-66° F.) and winter temperatures of 16.5°-19° (62°-66° F.).[4] That the winter temperatures were higher than the summer is attributable in part to the fact that these records were made in the mole instead of in the bay (as in summer), and experience shows that the water in the bay is one or two degrees colder than that in the mole. Also, doubtless, the temperature of the stream as a whole is slightly higher at the close of summer or in early winter than at the close of winter or in early summer, and it so happens that the Callao records were taken chiefly in early winter and in early summer.

The *Albatross* records of November 12-22, 1904, to be referred to again, were two degrees higher (19°, 20° C.) than my records of the same month in 1908.

A winter tourist might travel on the coast of Peru a distance equal to that from New York to Nassau or Miami, Florida, without finding a substantial difference in the temperature of the water for bathing. Thus, fifteen records at Paita (5° S.) in April and May, 1907 (end of summer or early winter), gave an average of 18.4°, and the lowest was 15.5°; while two records at Paita of December 29 and 30, 1907 (midsummer), were 17° and 17.5°, taken close to shore and about 8 P. M. A record at Chimbote (9° S.) in the same month of May was 17.5°; at Callao, May

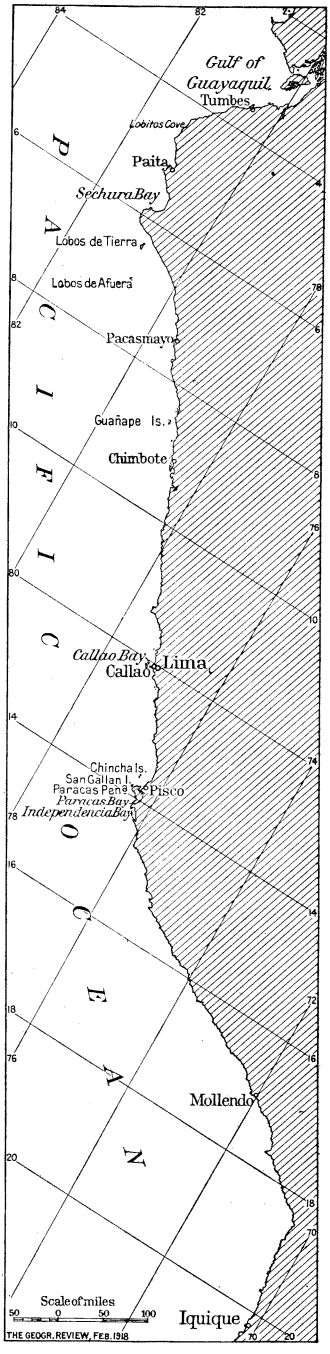

FIG. 1—Sketch map of the coast of Peru showing the location of the places mentioned in the text. Scale, 1:13,600,000.

[4] Compare the record for Callao shown in Fig. 76 of Isaiah Bowman's "The Andes of Southern Peru," New York, 1916. This record shows land and water temperatures from June to September, 1912.

20, 16.5°; while at Mollendo (17° S.) in midwinter, 1908, the water was at 16°.

While I have not such a systematic series of records as would justify inferences regarding the nature of the current, I can interpret the relations of 326 records taken at many points between Paita and Mollendo, from January, 1907, to July, 1908, only on the following tentative assumptions:

(a) That the Peruvian Current undergoes little change of temperature in traversing the 1,000 knots from Mollendo to Paita.

(b) That such differences as occur in my readings are due in small part to seasonal changes, likewise in small part to a want of temperature homogeneity in the current (with areas of warmer and colder water), or to the swinging of the stream toward or away from the coast (movements that are assumed by the fishermen), but in greater measure to entirely local influences. Allowance should probably be made, too, for differences from year to year according to the prevalence of icebergs in the southern seas or to other conditions affecting the stream at its origin.

Comparison of some "Albatross" Records of 1904

Examination of the dredging and hydrographic operations of the *Albatross* in this region in 1904[5] reveals an interesting fact. Near Sechura Bay (5° 46′ S., 81° 27′ W.) November 12, 1904, the surface temperatures were 63°, 64°, and 65° F. (17.2°-18.3° C.) in different localities. As the vessel sailed westward and southward across the Peruvian Current and away from the equator, the temperature rose to 69° at about the eighty-fourth meridian, 71°-72° at the eighty-sixth, 69°-73° at eighty-seven and a half, and 69°-70° near the ninetieth at latitude eleven to fourteen degrees south. Returning eastward, the temperature fell to 66° at about the seventy-eighth meridian and twelve degrees south. The records made in the region of 78° W. and 12°-13° S. (vicinity of Callao) were 66° and 68° F. Hence it appears that, although the *Albatross* went toward the source of the current for six degrees of latitude, from Sechura to Callao, the surface water was found to be 2° to 5° Fahrenheit warmer in the higher latitude, or farther removed from the equator, even near the coast. The explanation of this is not apparent. Again, in crossing the stream and passing into the central eddy, as it were, the water was found to be 7° or 8° warmer, although the latitude was about eight degrees higher.[6] It should be remarked, however, that these latter temperatures, being found farther off shore, were therefore in waters removed from the influence of any conditions that might cause an upwelling of colder bottom waters along the coast line.

[5] Dredging and Hydrographic Records of Fisheries Steamer *Albatross* for 1904 and 1905, *Bur. of Fisheries Doc. No. 604*, 1906, pp. 54-58.

[6] Compare the figures obtained by Capt. Paul Hoffmann and quoted by Hann (Julius Hann: Handbuch der Klimatologie, 3rd edit., 3 vols., Stuttgart, 1908-11; reference in Vol. 1, p. 173). The water temperature of 18.2° on the coast of Callao increased progressively to 27.0° at 135 nautical miles from shore.

Possible Significance of Vertical Currents

The possible significance of such a phenomenon has been called to my attention by Professor C. A. Kofoid. On the western shores of other continents its operation is evident. The case at first thought seems less clear for an upward movement of waters along the Peruvian coast. There is at no season a prevailing offshore wind, since the conditions are practically always such as to cause a drift of air from the colder water to the warmer land. We have, indeed, a practically uniform current with a following wind, paralleling or impinging against a generally unbroken coast line.[7] It is perhaps in the momentum or centrifugal force of the current, bearing against a westward-tending coast, that a cause of upwelling may be found. The effect of the momentum would be to cause the entire periphery of the stream to slide up the continental slope; but the water will not pile up against the coast to any great extent, because, under the influence of gravity, the surface waters would roll away from the coast, thus being continually replaced at the surface near the shore by waters from below. The practical result of these movements would be a slow peripheral upheaval, the direction tangential to the course of the stream and the curve a long spiral. Some evidence bearing on this suggestion might be obtained by comparison of temperature conditions at points farther south, where the coast line has no westward inclination, as at Iquique, Antofagasta, and Valparaiso. I do not find that there is in my records anything to throw

[7] It would seem important, however, to distinguish between the local development of the winds along the coast—where land and sea breezes play so prominent a part—and the conditions out at sea, where the trade wind drives the surface water from the southeast, inducing a compensatory rise to the leeward strong in proportion to the remarkable strength and development of the trades in the Southern Pacific. This would seem the basal influence, providing the conditions under which the local wind operates. On this question the references given by Hann (*loc. cit.*) should be consulted. It may here be noted that one of the strongest arguments in favor of the upwelling theory is the insignificant gain in temperature of the current as it slowly progresses from Valparaiso to Callao, a movement requiring four months. Capt. Paul Hoffmann (Otto Krümmel: Handbuch der Ozeanographie, 2nd edit., 2 vols., Stuttgart, 1907 and 1911; reference in Vol. 2, p. 715) found the November temperatures at Valparaiso and Callao to be 14.8° and 14.9° respectively. Again, Buchanan (*op. cit.*, p. 765) found the temperature from Coquimbo (30° S.) to Pisagua (19½° S.) to average 60° F. (15.6° C.), and along the coast from Independencia Bay northward the average was 61° F. (16.1° C.), though local variations were considerable.

In this connection a historical note may be of interest. The theory that the upwelling of cold bottom water causes the cool ocean temperatures off the lee coasts of the continents in mid-latitudes was first advanced, it would seem, in 1871 by the physicist E. Witte (*Poggendorff's Annal. der Physik und Chemie*, Vol. 142, 1871, p. 289) and in 1875 by Capt. L. E. Dinklage, later of the German Hydrographic Office in Hamburg (cf. A. Supan: Das kalte Auftriebwasser, *Petermanns Mitt.*, Vol. 37, 1891, p. 293). Later important discussions are to be found in Capt. Paul Hoffmann's "Zur Mechanik der Meeresströmungen an der Oberfläche der Ozeane," Berlin, 1884, and in A. Puff's "Das kalte Auftriebwasser," University of Marburg thesis, 1890. Through the researches of V. W. Ekman of Christiania (Beiträge zur Theorie der Meeresströmungen, *Ann. der Hydrogr. u. Marit. Meteorol.*, Vol. 34, 1906, pp. 423-430, 472-484, 527-540, 566-583) the theory has been placed on the firm foundation of mathematical analysis. It is accepted by such authorities as Hann (*op. cit.*), Krümmel (*op. cit.*), Supan (Grundzüge der physischen Erdkunde), and Sir John Murray (The Ocean). In this country it has been discussed, mainly in its application to the California Current, by Dr. G. F. McEwen (The Distribution of Ocean Temperatures along the West Coast of North America Deduced from Ekman's Theory of the Upwelling of Cold Water from the Adjacent Ocean Depths, *Internatl. Revue der gesamt. Hydrobiol. u. Hydrogr.*, Vol. 5, 1912, pp. 243-286; Peculiarities of the California Climate Explained on the Basis of General Principles of Atmospheric and Oceanic Circulation, *Monthly Weather Rev.*, Vol. 42, 1914, pp. 14-23; Oceanic Circulation and Temperature Off the Pacific Coast, in "Nature and Science on the Pacific Coast" (guide book for A. A. A. S. meeting in San Francisco, 1915), pp. 133-140.—Edit. Note.

much light, either in an affirmative or in a negative way, upon the question of the influence of vertical currents, if such occur, upon the surface temperatures. On the one hand, we do not find the variations we might expect where colder bottom waters are being drawn up to mingle with warmer surface waters. On the other hand, we have to admit that the absence of contrasting temperatures is not evidence that such movements do not occur, but only that they do not occur in such a way as to produce surface areas of markedly different temperatures; and this is what we should probably expect in view of the fact that the conditions tending to cause the vertical movements, if any, are practically uniform, except as they might be more pronounced where the shore line tended more sharply to the west or where the continental slope was steeper.

Direct Influence of Peruvian Current Upon the Coast

The Peruvian Current is not, like the Gulf Stream of the Atlantic, a remote influence as affecting the shores. It passes in close proximity to the coast, literally bathing the shores, and its effect is enforced by the general absence of shallows and enclosed bays where the coastal waters might be substantially warmed. It is a very evident phenomenon. The fisherman returning along the coast from a short trip to the north feels the force of the current distinctly. Steamers on the coast maintain a ten per cent higher fare for the southern journey than for a trip northward of the same length. Even in a small boat lying at anchor near an island the water may be observed to flow by like the current of a river. An equally striking manifestation of the current is gained when one observes from the heights of an island, such as one of the Guañapes, the line of surf-made foam streaming constantly away to the northward.

It is locally assumed that the current has certain swinging movements, and these are of considerable significance to the fisheries. *Cuando atraca el corriente* and *cuando se aleja* ("when the current approaches" and "when it recedes") are common terms among the fishermen, for such pelagic fishes as the *monito, sierra, albacore, dorado,* as well as the mackerel and *anchobetas,* may abound when the current "approaches," while they are less available when the current "recedes."

It would be interesting to know to what extent, if at all, the Peruvian Current may occasionally be pushed back or overflowed by the northern current. While I am without observations on this point, I would mention the following information furnished me in response to many inquiries. It is not uncommon for a current from the north—locally known as El Niño from its frequency during the Christmas season—to prevail in the region of Tumbes at 3½° S.; a reliable informant told me that he had witnessed a current from the north while at Lobitos Cove, just north of Paita (5° S.), which left on the beach quantities of drift with snakes, etc. Mr. Kaufmann at Pacasmayo told me he had known equatorial drifts and an alligator to

have been left on the beach there (7½° S.). He regarded the occurrence as remarkable but did not believe there had been any change in the direction of flow. He was inclined to suppose that the drift and the alligator had made a long journey after being carried out on the westward equatorial current.[8]

Indeed, an effective reversal of flow, bringing the warm equatorial or northern waters to displace the southern waters, could hardly be supposed to occur without affecting the fixed marine fauna and flora in a conspicuous and unmistakable way. There is, however, nothing inherently improbable in the supposition that under certain conditions the warmer and lighter equatorial waters might overflow the colder and heavier Peruvian Current to a more southern latitude than usual and thus bring the equatorial drift south to a point where, under the action of the winds, it would be thrown ashore at such a latitude as Pacasmayo. This might occur without manifestation of southward flow along the shore.

Data Bearing on Local and Seasonal Variations

The data of local variation in given seasons are of interest in this connection, and for convenience of examination the following tables are offered.

Maximum Local Variation		*Minimum Local Variation*	
Paita, bay protected on the south	5.0° C.	Pisco, bay protected on the south	2.0° C.
Chimbote, bay largely enclosed	4.5	Callao, bay protected on the south	2.0
Pacasmayo, bay with little protection	4.6	Independencia Bay, bay largely shut in from ocean	1.0
Lobos de Afuera, bay between islands 30 miles off shore	3.4 to 3.0	Mollendo, on very exposed shore	0.0
		Lobos de Tierra, islands 12 miles off shore	0.5 to 1.0
		Chincha Islands, islands 10 miles off shore	1.5

Intermediate Degree of Local Variation

Callao, bay partially protected	2.5° C.
Guañape Islands, islands about 10 miles off shore	2.5° C.

These data are puzzling only at first glance. We find the maximum local variation where eddies are to be inferred: Paita Bay, Chimbote Bay, Pacasmayo Bay, Lobos de Afuera Bay. We find minimum local variation where the stations are exposed: Mollendo, Chincha Islands, Lobos de Tierra. (It is to be remarked that at both the Chincha and Lobos de Tierra Islands the temperatures were taken on the inshore sides, not protected from a

[8] The northern current has also attracted a certain amount of scientific notice. Following the observations of Lartigue, 1822, Ray, Fitz Roy, Findlay, and others have remarked on its peculiarities. In 1891 the extraordinary rains of the north Peruvian coast were associated with an intense development of the current. Interest awakened by the occurrence took shape in papers contributed to the *Bol. Soc. Geogr. de Lima* (Luis Carranza: Contra-corriente marítima, observada en Paita y Pacasmayo, Vol. 1, 1892 pp. 344-345; Camilo N. Carrillo: Hidrografía oceánica, Vol. 2, 1893, pp. 72-110; F. A. Pezet: La contra corriente "El Niño" en la costa norte del Perú, Vol. 5, 1896, pp. 457-461.

north or south current but protected from any movement with a tendency east or west.) We also find little variation in Independencia Bay, but the openings are at the northern and southern extremities of a long bay. Callao Bay, being open to the current on the south, is less liable to an eddy; the same cannot be said of Pisco Bay, but the shore current there passing through the straits between Paracas Peninsula and San Gallan Island may affect the mainland shore as far as the port of Pisco, though there is an undoubted eddy in the southern extremity of the bay. Guañape alone offers a somewhat greater degree of variation than we should expect by comparison with Lobos de Tierra below and the Chincha Islands above.

It is inconceivable that the surface temperature could remain so little affected while the current traverses so great a distance, except there occur an intermingling of waters from below; yet, if any inference can be drawn from the observations here offered, it must be that the vertical movements are not localized but are generally distributed and perhaps continuous. The exact nature and the vertical extent of the movements certainly await further investigation.

Data bearing on seasonal variations are expressed in the following tables, giving the difference between averages taken at given localities in different seasons of the year:

Table of Seasonal Variations

Lobos de Tierra, April, Dec.	1.7° C.	(see below)
Lobos de Afuera, March, Nov.	2.3	" "
Callao, various months	1.6	" "
Chincha Islands, June 1907, July 1908	1.3	" "

Lobos de Tierra, March, April 1907, average of 20 readings	20.5° C.
" " Dec. 1907, " " 4 "	18.8
Difference	1.7° C.

Lobos de Afuera, March 1907, average of 31 readings	20.5° C.
" " Nov. 1907, " " 12 "	18.2
Difference	2.3° C.

Callao, Jan.	1907, average of	10 readings	16.5° C.
Oct.	"	9	16
Nov.	"	6	16.7
April	1908,	15	17.6
May	"	24	17.4
June	"	26	17.3
July	"	4	17.4

Difference at Callao between lowest monthly average (16°) and highest average (17.6°) ..... 1.6° C.

Isolated records are not included.

Chincha Islands, June 1907, average of 11 readings	16.1° C.
" " July 1908, " " 6 "	17.4
Difference	1.3° C.

The data bearing on local variations, some of which have already been given, grouped into maximum and minimum values, are here cited more fully in geographical order. The following table expresses the difference between extreme temperatures taken at a given locality in one season. Such variations are much more pronounced than the difference of averages at different seasons. It is to be remembered, however, that these variations cannot be attributed to the condition of the weather nor, ordinarily, to the time of day when the record was made.

Table of Local Variations (In Geographical Order)

LATITUDE	PLACE	MONTH		READINGS	VARIATION
5°	Paita	April	1907	15	5.0° C.
6½°	Lobos de Tierra	April	"	20	0.5°
	Lobos de Tierra	Dec.	"	4	1.0°
7°	Lobos de Afuera	March	"	31	3.4°
	Lobos de Afuera	Nov.-Dec.	"	12	3.0°
7½°	Pacasmayo	March	"	14	4.6°
8½°	Guañape Islands	March	"	10	2.5°
9°	Ferrol (Chimbote)	March	"	12	4.5°
12°	Callao	April	1908	15	2.5°
	Callao	June	"	26	2.0°
13¾°	Pisco	June	1907	11	2.0°
13¾°	Chincha Islands	June	"	11	1.5°
	Chincha Islands	July	1908	6	1.5°
13¾°	Ballestas Islands	May-June	1908	11	3.0°
14¼°	Independencia Bay	June	"	8	1.0°
17°	Mollendo	July	1908	4	0.0°

Generally, as may be seen, the amount of variation (changes of temperature of the water in a given locality, without change of season) is greater in the regions of lower latitudes than in those of higher latitudes.